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OFFSHORE PETROLEUM INSTALLATIONS

by Jack S. Toler

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OFFSHORE PETROLEUM INSTALLATIONS

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Synopsis

The development of the petroleum resources lying offshore from the coasts of Louisiana and Texas has presented many problems to the engineering profession. The large and prolific reservoirs of oil and gas located and developed inshore along the Gulf of Mexico indicate that many areas equally or more productive are to be found offshore. Financial and operational risks involved in locating and recovering these resources are such that large-scale exploratory and development work did not appear to be justified prior to 1942. Following World War II, however, demands for petroleum and petroleum products made it necessary for the petroleum industry to develop engineering and operating techniques for drilling below the Gulf of Mexico.

Introduction

Drilling operations conducted prior to 1942 in the comparatively shallow depths off the coasts of Louisiana and Texas brought attention to the many operational problems in open-water drilling. These operations led to greater recognition of the need for careful study of both structural design and foundation design, and of the need for the development of special construction techniques and seagoing construction equipment. It is necessary only to view the destructive results of a hurricane along the "Gulf Coast" of the United States to understand the limitations of conventional design and operation procedures, particularly in the more exposed areas offshore from the 30-ft depth contour.

Before the petroleum industry ventured to move its operations into the deeper waters of the Gulf of Mexico, its engineering staffs, private engineering firms, and consultants spent several years developing reliable criteria concerning wave action, analyzing the soft silt-clay strata underlying the Gulf of Mexico, and studying various foundation and structural designs. The first operations were conducted in 1948, from 6 to 8 miles offshore, in depths greater than 30 ft of water. These operations followed research and study without benefit of precedence and actual experience. The concern for the safety of the fifty-man

drilling and technical crews and the huge investments in platforms and rig equipment made many operators apprehensive lest some unknown critical design factor had not been considered. Most companies considered costs second to safety in the design and operations of the initial phases, feeling that with the knowledge and information gained through experience, techniques would subsequently be developed to reduce costs to compare favorably with marsh and inshore water drilling.

During the period from 1947 to 1952, many advancements were made which more clearly defined the engineering problems in drilling and production operations. The principal considerations are as follows:

1. Oil and gas must be located, produced, and delivered to inland terminals at a cost that will assure the operator a profitable return on his investment.
2. Operating plans should accommodate the conditions imposed by the particular location, depth of water, and proposed development (whether exploratory or field development).
3. Drilling equipment and rig arrangements should be designed to afford maximum utility on a minimum of deck area, and to distribute loadings for the safest and most economical design of both the foundation and the structure.
4. Criteria for design should be further developed and standardized, particularly with reference to the intensity and the nature of the loadings imposed by wave forces on exposed foundation and structural members.
5. Greater understanding of the characteristics of the soils underlying the Gulf of Mexico bottom is required for more economical design of the deep-penetration high-bearing pile supports.
6. Structural design and construction techniques should afford a maximum of economy in materials, fabrication, and construction operations.
7. Construction equipment should be seaworthy and able to operate continuously during ordinary rough seas. The equipment should be maneuverable and able to withstand storms of hurricane intensity.
8. Adequate protection should be provided against the corrosive effects of salt water and atmosphere.

Considerable progress was made from 1947 to 1952 in the development of design criteria, structural design, and design and layout of drilling equipment. Safety and efficiency in drilling operations were also greatly increased. More must be done in the field of engineering research, however, to assure the development of the most adequate and economical installations for deep-water operations, and to make possible operations in water depths greater than present (70 ft) operating depths.

Prior to 1953, the petroleum industry had invested more than $261,000,000 for leasing, exploration, and development offshore along the Gulf Coast. During the years of the "tidelands" controversy, the United States Congress was unable to pass legislation to fix ownership or to establish necessary procedures for interim operations. The importance of the tidelands in the development of the petroleum resources of the United States is apparent in the fact that, from 1947 through 1951, a total of 242 wells were drilled with approximately 130 completed as oil, gas, or gas-condensate producers. More than twenty producing areas were discovered in Gulf of Mexico waters during this same period.

To continue these operations, approximately seventy separate drilling platforms have been erected (as of January 1, 1953) in water depths to 70 ft. A number of the larger platforms cost more than $1,250,000. Several costly oil and gas pipelines were built to carry the products to shore terminals. One of the larger fields was electrified by the construction of high-voltage transmission lines across many miles of marshland and into the Gulf of Mexico.

Actual drilling operations in the tideland area of Louisiana and Texas have been conducted by seventeen oil companies. A number of other companies hold leases or have performed geophysical exploration in the area. The operating problems have, in general, been the same. However, the development of engineering and operating techniques by the operators has varied considerably. This paper treats primarily with the design considerations, methods of construction, and operating facilities in use by one of the major companies engaged in offshore petroleum operations.

Early Operations in the Gulf of Mexico

One of the first drilling operations in the Gulf of Mexico was conducted in 1938 off McFadden Beach near High Island, Tex. Five wells were drilled in this area, the one farthest offshore being 7600 ft from land in 18 ft of water. The five wells were drilled from conventional type timber-pile foundations and structures similar to those used for inland bay drilling and marsh drilling. In 1938 there was very little reliable oceanographic or soils data available for guidance in design. As can be seen in Fig. 1, the unobstructed spacing between pile supports and the structural members above mean sea level was limited by the low-strength timber construction used. A total of 100 piles, 65 ft long, was used to support the 70-ft-by-122-ft drilling deck set 15 ft above mean Gulf of Mexico water level (MGL). In comparison, a structure erected in the Gulf of Mexico, approximately 6 miles offshore from Grand Isle, La., is located in 55 ft of water and has a 60-ft-by-80-ft deck 44 ft above MGL. The structure was supported by a templet-type foundation with sixteen 10-in.-by-57-16 steel piles, 275 ft long. The piles are driven with a penetration of 180 ft and have a cutoff at El. 40 MGL.

Although these conventional, inland platforms provided foundations for successful drilling operations, they were inadequate for conditions imposed by the frequent storms and gales; operations were handicapped by damage and loss of drilling time incurred during rough seas. A number of intense storms and hurricanes have been experienced which would have, in all probability, destroyed the original installations at McFadden Beach.

There were a number of other early operations in water depths of 20 ft along the Gulf Coast, notably those in the Creole Field off the coast from Cameron, La. Approximately twenty-five wells were drilled from conventional pile foundations in shallow waters off the Gulf Coast from 1937 to 1942.

Design Considerations

Wind and Waves.—Design criteria in general use prior to the fall of 1949 were based on a probable maximum wave height of 32 ft, with a 5-ft storm tide in water depths of 40 ft, giving a maximum crest height of 29 ft above MGL. It was considered possible that a storm of long duration, with wind velocities

above 125 miles per hr, would develop tide and wave heights considerably greater than those previously listed. Based on a study of hurricanes along the Gulf Coast, it was considered unlikely, however, that storms generating wave-crest heights in excess of 29 ft above MGL would occur on a frequency of more than once in 40 to 50 years.

In October, 1949, a small but intense hurricane formed in the Gulf of Mexico off the coast of Merida, Mexico, and moved in a northerly direction to the coast of the United States in the vicinity of Freeport, Tex. Data obtained at a drilling site located in the path of the storm revealed wave-crest heights which closely approximated the maximum heights previously considered probable. As a result of the 1949 hurricane, a number of designers changed their criteria and increased their wave-force computations to provide for a probable maximum 40-ft wave with a 10-ft storm tide in water depths of 65 ft above MGL. This would produce a breaking wave with a crest height of 40 ft above MGL.

Although most engineers agreed on the safe limits of probable maximum wind-and-sea conditions to be expected, they differ widely in their interpretations of available theoretical data concerning the action of waves, and in their understanding of the severity and exact nature of the loadings imposed upon structures during storm periods. A curve for the design of a permanent drilling platform is shown in Fig. 2.[2,3] This chart shows the wave profile

[2] "The Solitary Wave Theory and Its Application to Surf Problems," by Walter H. Munk, *Annals*, New York Academy of Sciences, Vol. 51, May, 1949, pp. 376–424.

[3] "Wave Action on Structures," by Walter H. Munk, *Petroleum Development and Technology*, Am. Inst. of Mining and Metallurgical Engrs., 1949, p. 11.

and pressure diagram for a wave 40 ft high, 380 ft long, with a period of 9 sec in 65 ft of water with a 10-ft storm tide. The pressures shown are maximum, and they occur at the crest of the breaking wave on a tubular pile 1 ft in diameter. For cylindrical sections of other sizes, the forces shown should be multiplied by the diameter in feet. The pressure resultant is 9,008 lb acting on the pile 12.36 ft above MGL. A factor of 5.9 is used in computing the forces on flat surfaces. This criteria curve is by no means accepted as final, nor is it universally used; some designers use forces of less magnitude, whereas the criteria used by others give considerably greater forces—especially with respect to the unit pressures between zero and 35 ft above MGL.

Three storms of near- or above-hurricane intensity were experienced between 1947 and 1952 in areas where drilling platforms were located. There was evidence of wave heights from 22 ft to 29 ft above MGL. From observations of the wave effect on the structures lying within the storm paths, one fact appears to be significant: Extensive damage and destruction were sustained by those installations with flat deck and structural surfaces exposed to the forces of the waves, whereas those with deck and superstructure set above wave height were relatively undamaged. The effects of these storms enabled engineers to review certain basic design factors in the light of actual conditions. The difficulty in obtaining measured (or observed) data at the height of storm periods, or under laboratory conditions, however, has limited the accumulation or verification of other facts necessary for agreement among criteria designers. Further development of the factors involved in the design for wave forces is essential to more complete and uniform understanding among those engaged

in design.

Foundation.—Prior to 1946, little reliable data was available concerning the characteristics of the soil below the Gulf of Mexico. Several different procedures had been followed by various operators in conducting soils investigation. These investigations depended on the operator's scope of operations and the proximity of the operator's locations to the delta formations of the large silt-carrying streams, where erratic strata of sand, silt, and clay can be expected.

In order to obtain data for foundation design, Raymond F. Dawson,[4] M. ASCE (in 1946 and 1947), aided in the investigation of the soils below the Gulf of Mexico, in an area extending from the west side of the Mississippi River delta west to Timbalier Bay, in Louisiana. Seven core-test holes were drilled at various points on land between Tiger Pass in Louisiana and Timbalier Island. Another core test was drilled from a platform constructed on a 24-in. test pile driven approximately 6 miles offshore from Grand Isle, La. To supplement the core-test information, 24-in. tubular test piles were driven in the Gulf of Mexico at ten prospective platform locations. The core tests were drilled to depths of approximately 400 ft, and the test piles were driven with penetrations of 165 ft.

[4] "Report on Soil Tests from Timbalier and Tiger Pass," by Raymond F. Dawson, Humble Oil and Refining Company, November, 1947.

Unconfined compression tests of the samples collected by Mr. Dawson were used to measure shear strengths of the soils, and consolidation tests were made to aid in determining the probable maximum settlement to be expected. It was found that, except for surface variations, the soil formations throughout the area investigated consisted of a soft, silty clay having a comparatively low shear strength and extending 200 ft or more below the Gulf of Mexico. Although the soil profiles were not uniform, there was sufficient similarity in all borings to furnish reliable average values of cohesion. The average value of cohesion from various depths of penetration to the floor of the Gulf of Mexico was determined by use of the average of all borings taken. This average value of cohesion was used as a guide in determining the depth of penetration required for individual piling loads at various platform locations. Borings taken over the area investigated indicated the absence of a thick stratum of dense sand to furnish end bearing for piles—therefore, all piles are considered to act as friction piles.

Driving data recorded on piles show that the driving characteristics of individual 10-in.-by-57-lb steel H-piles are very irregular for the first 125 ft to 135 ft of penetration, with appreciably low resistance to driving. Resistance gradually increases and driving characteristics become more uniform as penetrations of approximately 185 ft are approached. This trend indicates that when sufficient penetration is reached, the average soil conditions in the area are such that uniform results are obtained, even though the formations may be of an irregular nature. It would appear, however, that these average conditions should not be relied on where foundations are to be built near the outlets of large, silt-carrying streams such as the Mississippi and Atchafalaya rivers, because of the extremely erratic soil formations to be encountered. Near such outlets borings should be taken at the location either prior to, or at, the time when the platform is to be erected. The pile penetrations should be determined

from an analysis of the borings.

Soils studies were continued by Mr. Dawson in 1949, in order to determine more exactly the characteristics of the shallow formations in the floor of the Gulf of Mexico. Offshore borings were made at several locations, to depths of approximately 50 ft below the bottom. The results of the borings indicated a predominance of soft, silt clay, with cohesive strengths varying from 40 lb per sq ft to 400 lb per sq ft.

Based on this study, and as an additional factor of safety, modifications were made in later templet-type foundations to reduce the possibility of excessive bending stresses under maximum storm loading conditions. These modifications included increasing the length of the templet legs to provide a penetration of 27 ft, and increasing the area and strength of the templet legs below the mud line. On existing installations the soft soils were strengthened and consolidated by placing an 18-in. layer of shell and a 3-ft layer of 6-in. crushed rock on the floor under and around the foundations.

Operational Facilities

Drilling and producing operations offshore involve engineering study and advance planning, with consideration given to location, depth of water, drilling depths, and the operator's plan for development—whether exploratory or field development drilling. In addition to constructing a drilling platform, it may be necessary to provide moorings for drilling tenders and barges, oil storage batteries, marine pipelines, and land terminal facilities from which operations can be conducted. Experience has proved that these accessory facilities are costly and that as much attention must be given to their design and installation as is given to the drilling platform itself.

Drilling Platforms.—Drilling operations have followed two plans: (1) The use of a large self-contained platform with crew quarters, mess facilities, drilling equipment, pipe and mud storage all contained on the platform; and (2) the use of a small platform to contain the minimum of rig equipment with the pumping equipment, pipe and mud storage, living quarters, and other required service facilities placed on a moored drilling tender. Although some operators have preferred one type of platform over the other for economy or convenience in operation, each type has a place in the overall development of a productive area.

One of the first deep, wildcat, offshore operations was conducted from a large, double-deck, self-contained platform erected 7 miles south of Grand Isle in a water depth of 48 ft. Although four producing wells were drilled from this platform, and several additional wells were proposed, the large investment involved in such an installation is considered prohibitive to wildcat drilling where the first well drilled, if dry, might result in abandonment of the prospect. The operations conducted prior to 1952 were primarily exploratory and subsequent drilling was performed with a smaller type of platform and World War II surplus landing ships used as drilling tenders.

The first drilling-tender platforms were 50 ft by 150 ft. They provided drilling positions for three wells spaced 10 ft on centers in the longitudinal direction of the platform. A 50-ft-by-50-ft area at the forward end of the platform was used for pipe storage, with rig equipment arranged in the 50-ft-by-

100-ft space at the rear. At a number of drilling locations the pipe-storage space was eliminated and the pipe was moved directly from the tender to the derrick floor. Later developments resulted in a much more satisfactory arrangement; the rig and the equipment were placed on a 90-ft-by-120-ft deck, with well centers alined with the transverse axis of the structure. This arrangement provided five drilling locations, and increased the deck space by 45%. The platform cost was slightly less than that of the 50-ft-by-150-ft, three-well platform. A number of smaller single-well platforms were erected for drilling wells to shallow depths where no directional drilling was anticipated.

Also built were eighteen single-deck drilling-tender platforms for exploratory drilling in the Louisiana area. Many changes made in the rig arrangements and the equipment layouts let to greater economy in operations and lower "per-well-platform cost." A 60-ft-by-80-ft platform was constructed without pipe racks. This platform was designed to support a heavy rig for drilling wildcat tests to 14,000-ft depths. This layout and design permit the drilling of two wells with an approximately 50% reduction per-well-platform cost. Initial construction plans were designed to make possible platform extension to 90 ft by 120 ft with pipe racks and drilling locations for five wells, in the event that extensions be desired later, to provide a 120-ft-by-120-ft self-contained platform for drilling a total of ten wells. Significant features of this plan were: (a) A minimum platform investment was made in drilling the first well, and, in the event that the prospect was dry and abandoned, all materials with the exception of the piling below mud line could be salvaged for use elsewhere; and (b) in the event that drilling the initial well yielded production, and additional directional wells were desired, the platform could be expanded to a 90-ft-by-120-ft five-well structure without loss of drilling time, while the second well was being drilled from the initial platform.

A two-well platform similar to that described was used for drilling at Grand Isle Block 16, State Lease 799 F-1. Its deck, set at El. 44 MGL is supported by sixteen 10-in-by-57-lb steel H-piles driven through the legs of four 10-ft-square-by-80-ft-long pipe templets.

Drilling tenders used in conjunction with the smaller platforms have been landing vessels converted to accommodate drilling operations. The barge is moored with its bow approximately 25 ft from the end of the platform, and is connected to the platform by a movable ramp carrying walkway and pipe chute. A 35-ton-capacity gantry crane is installed near the bow of the vessel and is used to load cargo and supplies and to transfer material to and from the platform. The design of the drilling-tender moorings is critical, as these moorings must be strong enough to hold the vessel in safe position under extreme wind-and-sea conditions. Arrangements must be made to swing the stern of the barge through a considerable angle so that its axis can be held as nearly parallel as possible to the sea current direction. Fixed moorings with high-test anchor chains connected to heavily-reinforced spud piles driven into firm soil well below the Gulf of Mexico floor have provided satisfactory moorings for the drilling tenders.

Offshore drilling operations have been conducted from multiple-well platforms rather than from single-well platforms, with the first well being drilled vertically into the geological formations. Additional wells can then be drilled

by directional methods to other drilling objectives. Although the cost of drilling directional wells is usually greater than straight-hole drilling, analysis of costs indicates that it is more economical if more than one well is to be drilled in a given area.

Experience has shown that drilling from self-contained platforms is more efficient than from drilling-tender platforms. However, the cost of this type of installation is such that the tender-type platform is more economical for the drilling of a limited number of wells. In an area where extensive field drilling is contemplated and drilling depths are such that a number of wells can be drilled directionally, cost analysis may indicate that directional drilling would be more economical from a self-contained platform than from any other type.

Conclusion

Offshore petroleum operations have presented many unusual problems in the fields of civil, petroleum, and marine engineering as well as in the associated field of oceanography. At the outset of deep-water operations, there was little experience to guide operators in planning their operations and in designing their installations to withstand the forces encountered in the open waters of the Gulf of Mexico. Experience gained through actual construction and drilling operations has greatly increased the knowledge of essential design factors and has furthered the development of operating techniques. These techniques will permit profitable development of the offshore petroleum reserves in the Gulf of Mexico. Further study and investigation of design factors involved are requisite, however, to a common understanding among the engineers engaged in offshore operations. This need will be intensified in the case of installation development beyond the water-depth limit for pile foundations.

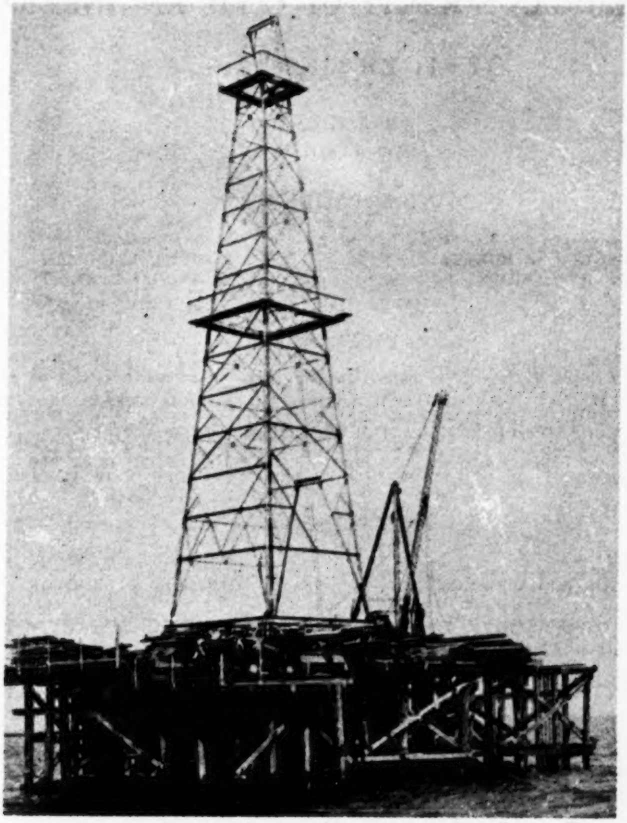

FIG. 1.—DRILLING PLATFORM LOCATED OFFSHORE FROM HIGH ISLAND, TEX.

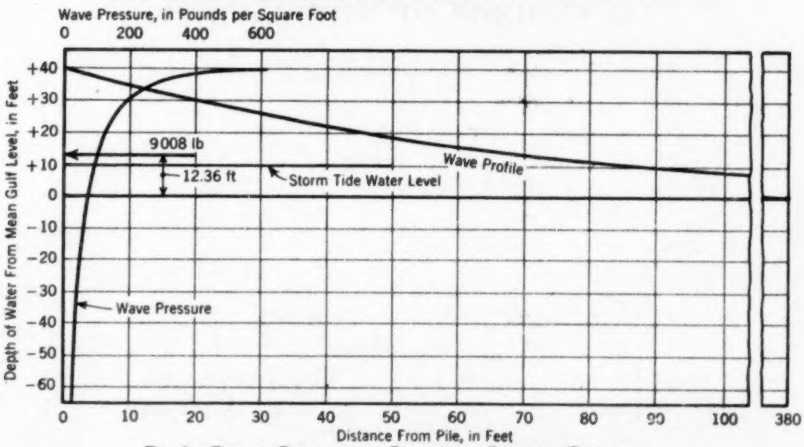

FIG. 2.—DESIGN CURVE FOR A PERMANENT DRILLING PLATFORM

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